

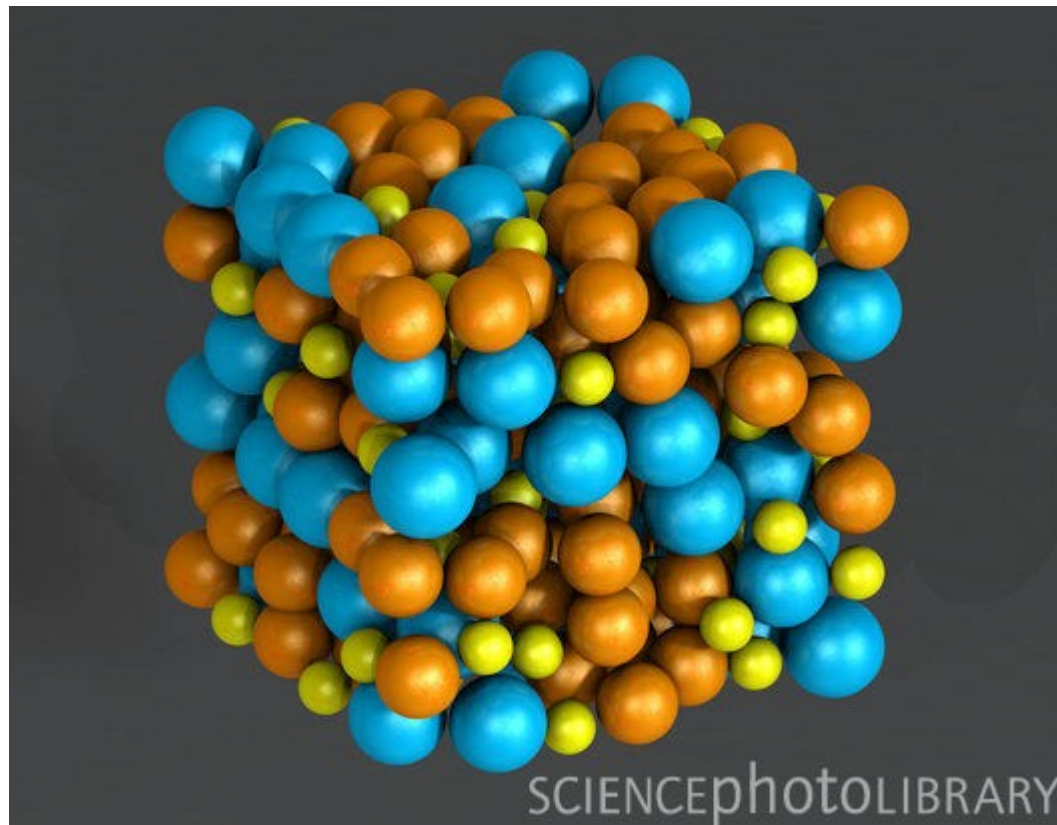
# Nanomatériaux

Anaël Lemaître

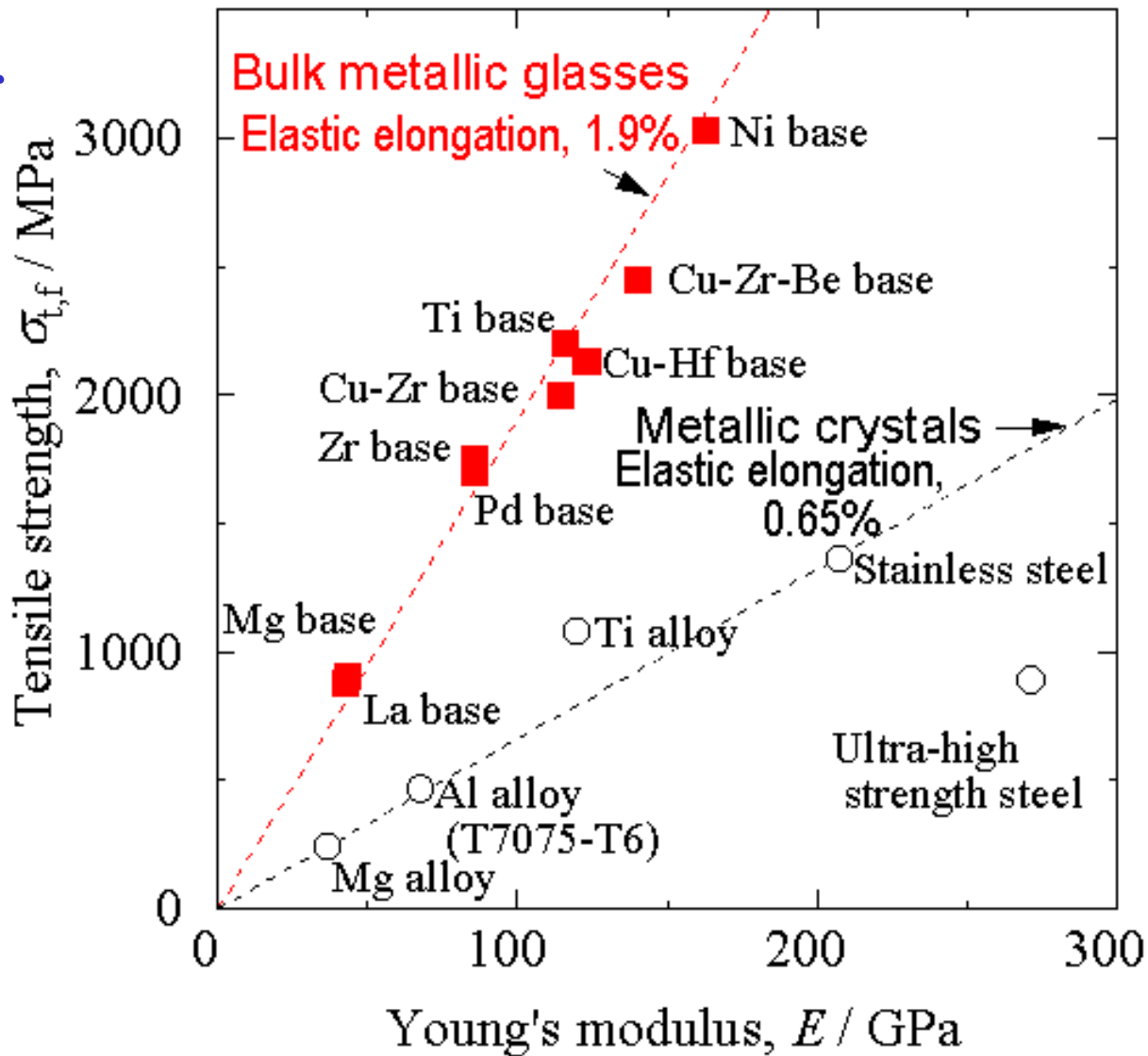
# Plan du cours

- Top-down: éléments de thermodynamique
  - Cristallisation
  - Équilibre thermodynamique d'un alliage
  - Décomposition spinodale
- Bottom-up:
  - Interactions élémentaires et cohésion des solides
  - Méthodes numériques
- Mécanismes élémentaires de la déformation
  - Élasticité
  - Plasticité/fluage

# Solides non-cristallins



Verr



# Embossage:

- verre métallique (base Pt)
- - par mousse d'Al

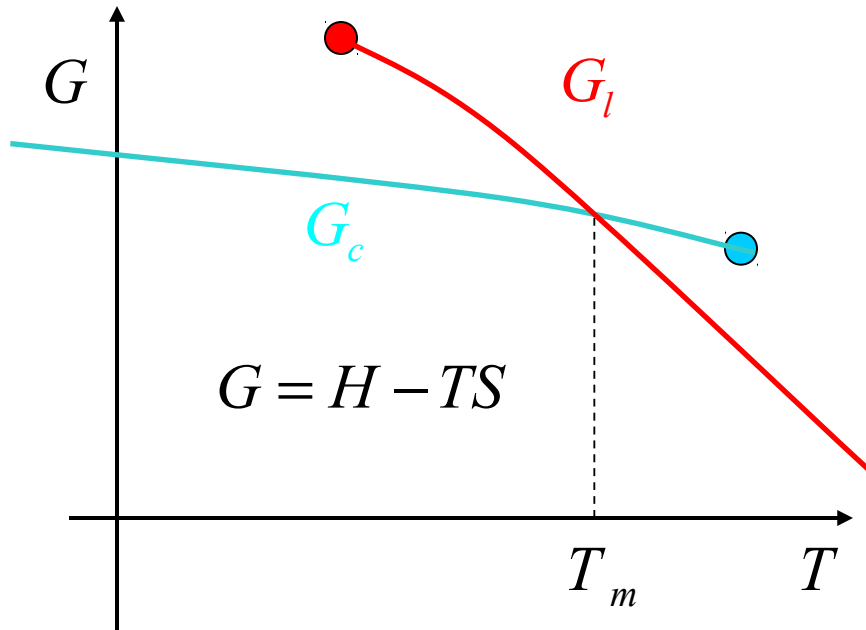
## Application

- créer des motifs à 13 n
- au lieu de 45 nm sur S

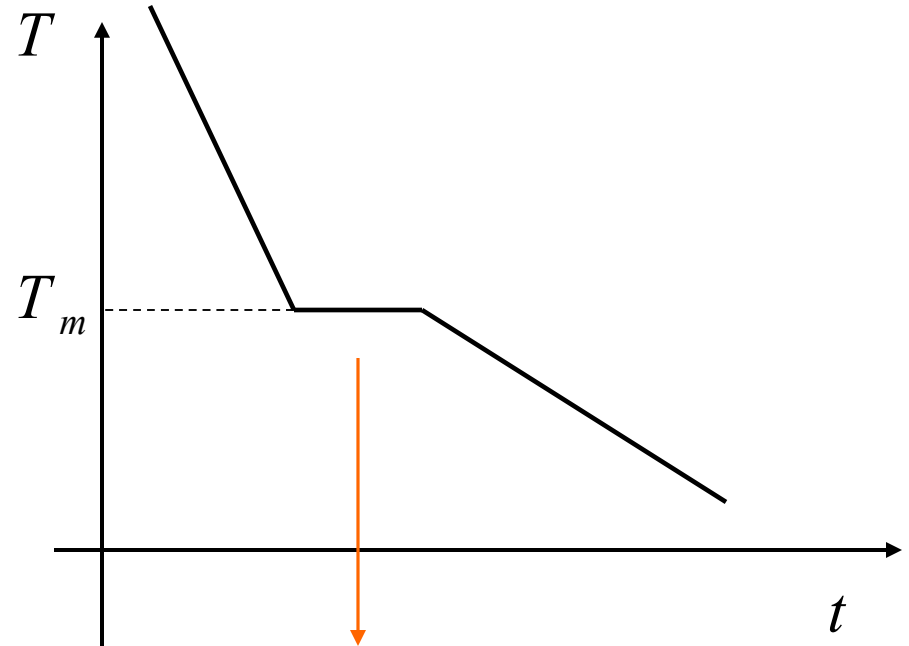
Acc V Spot Magn Det WD Exp  
10.0 kV 8.0 17308x SE 11.0 1

|-----| 2 µm

# Chaleur latente



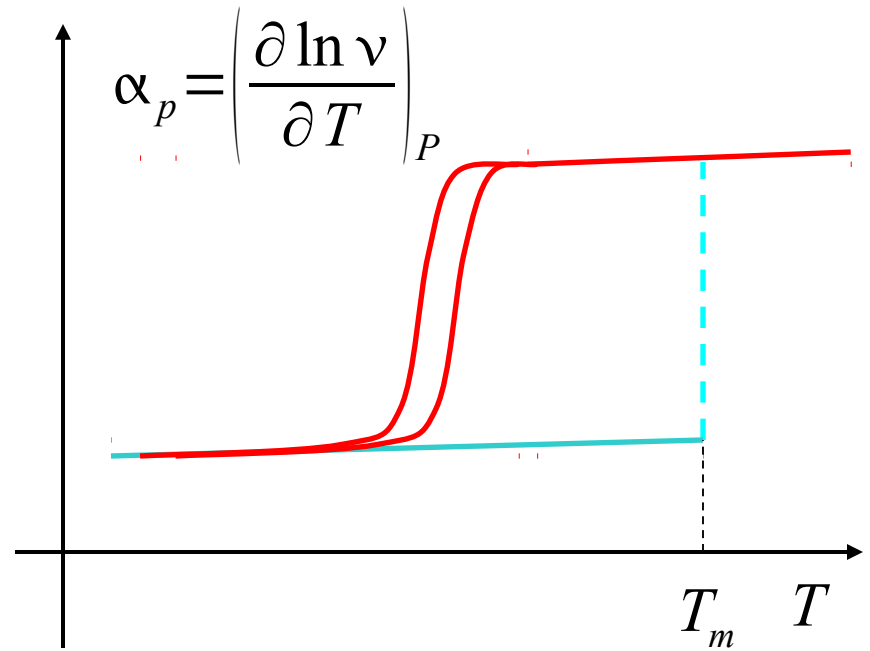
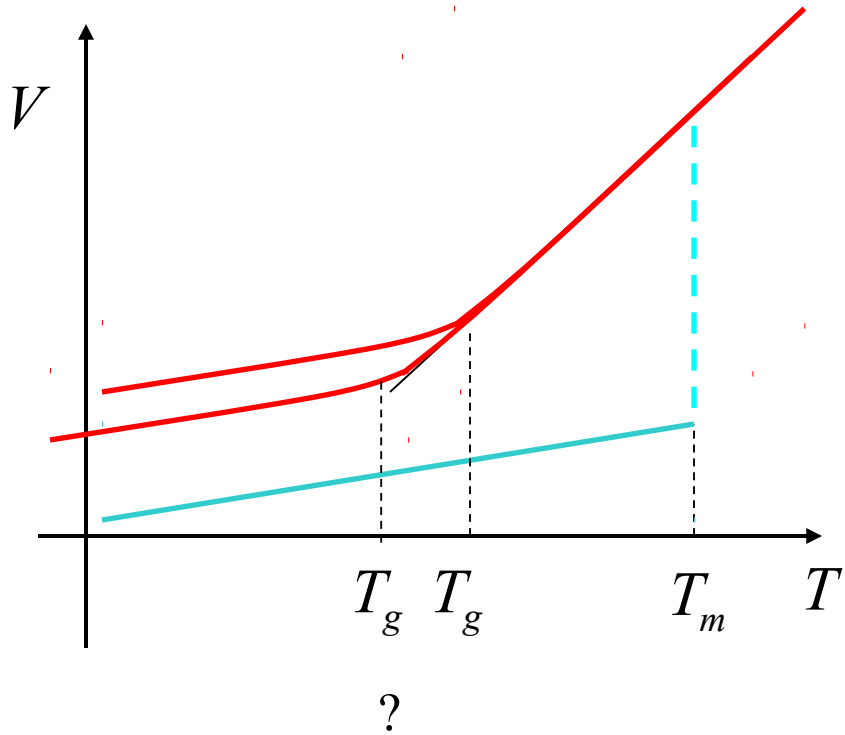
Par définition: 
$$\frac{\Delta G}{\Delta T} = S$$



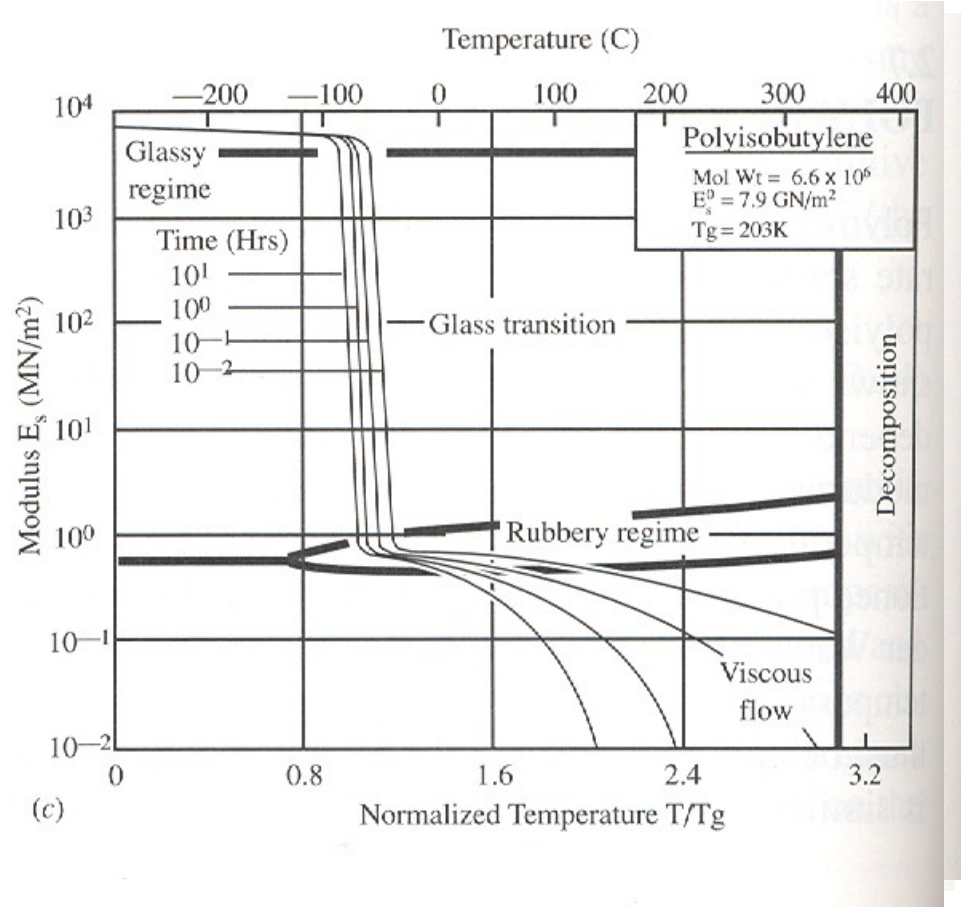
Chaleur latente

$$\delta Q = T_m (S_l - S_c) = H_m > 0$$

# Refroidissement isobare



# Élasticité

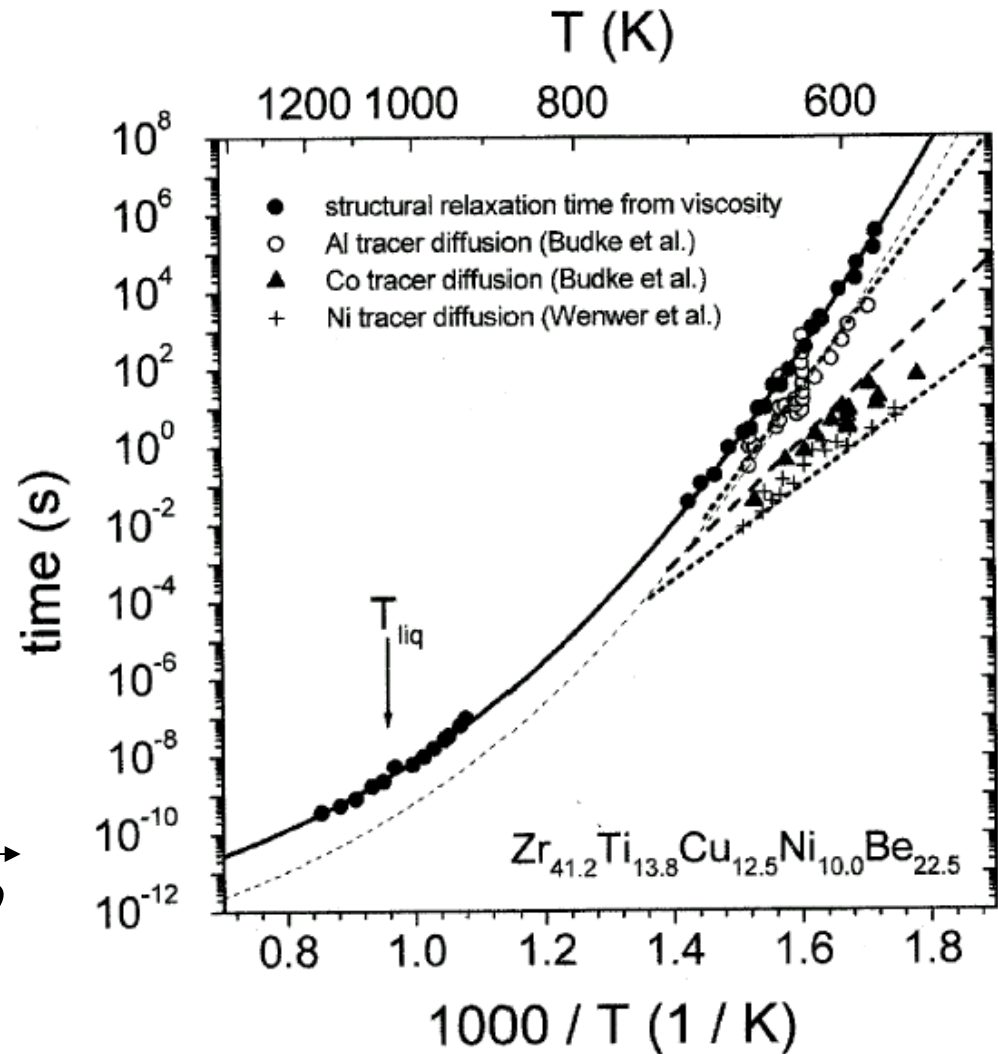
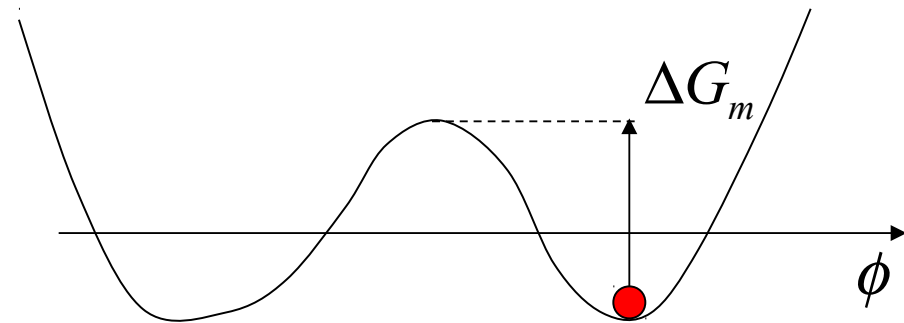




# Relaxation des liquides surfondus

On fera l'hypothèse que la diffusion des atomes au sein du fluide est un processus activé, de type Arrhénius.

$$\omega_L = \omega_0 \exp\left(-\frac{\Delta G_m}{kT}\right)$$



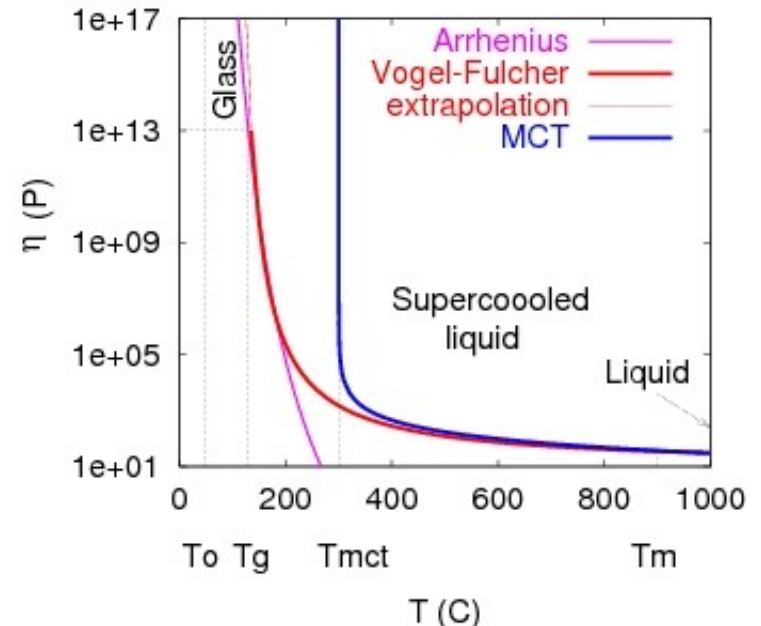
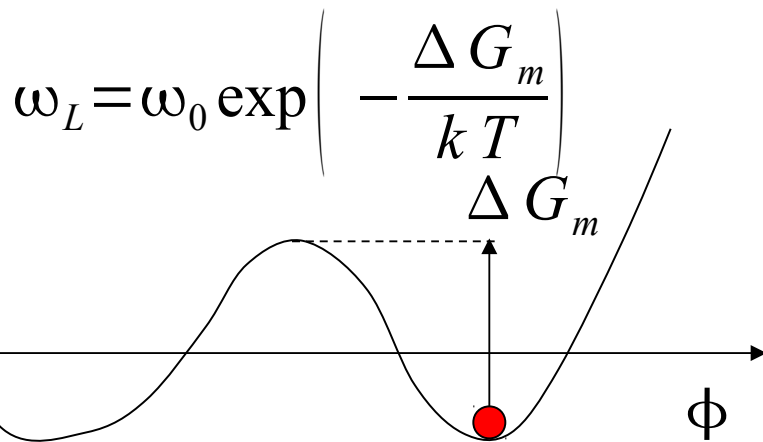
# Relation d'Eyring

C'est un calcul qui est à la base de toutes les théories de fluage dont nous avons parlé:

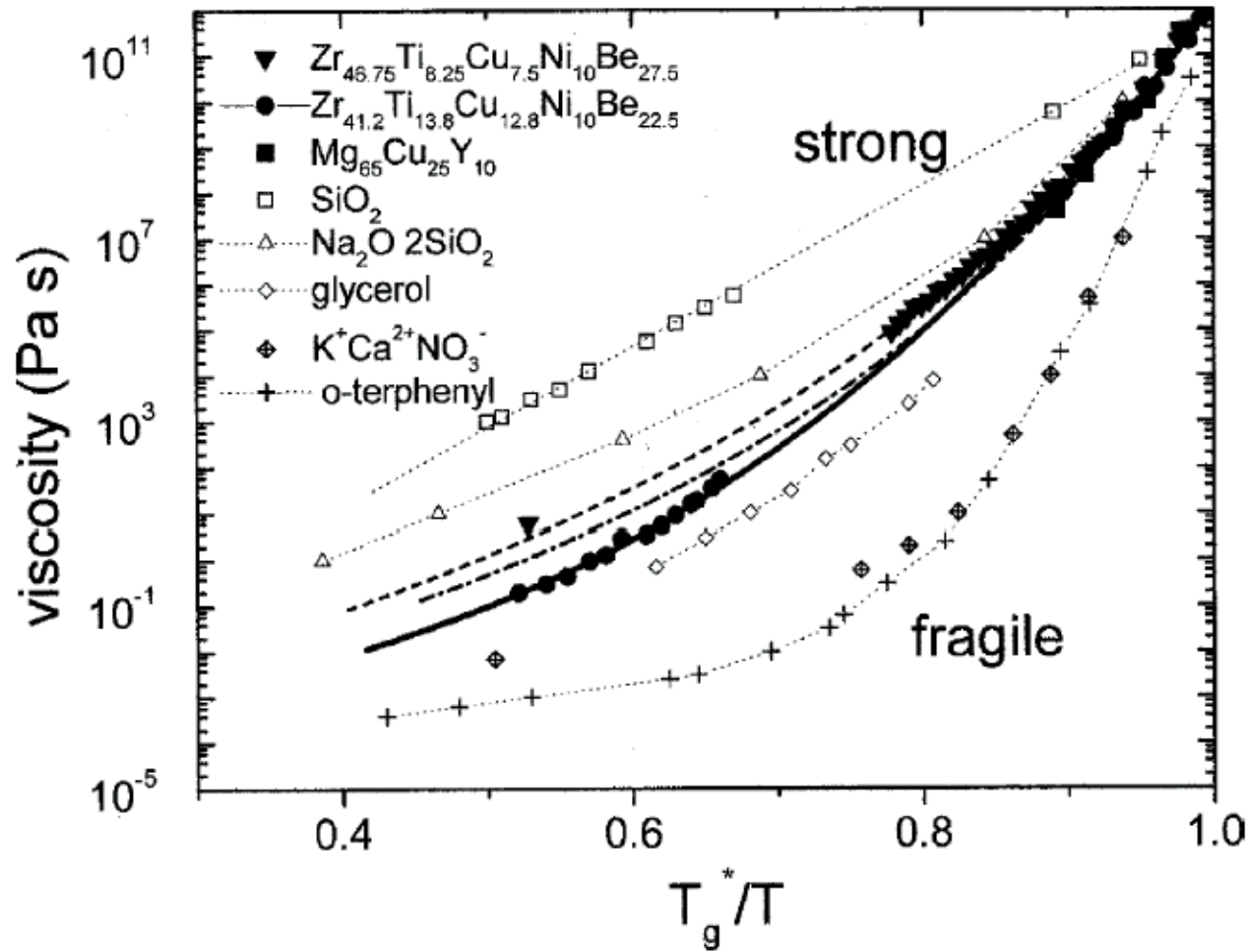
$$\dot{\epsilon} = \omega_0 \exp\left(-\frac{\Delta G_m}{kT}\right) \left(\frac{\sigma \Omega}{kT}\right)$$

⇒

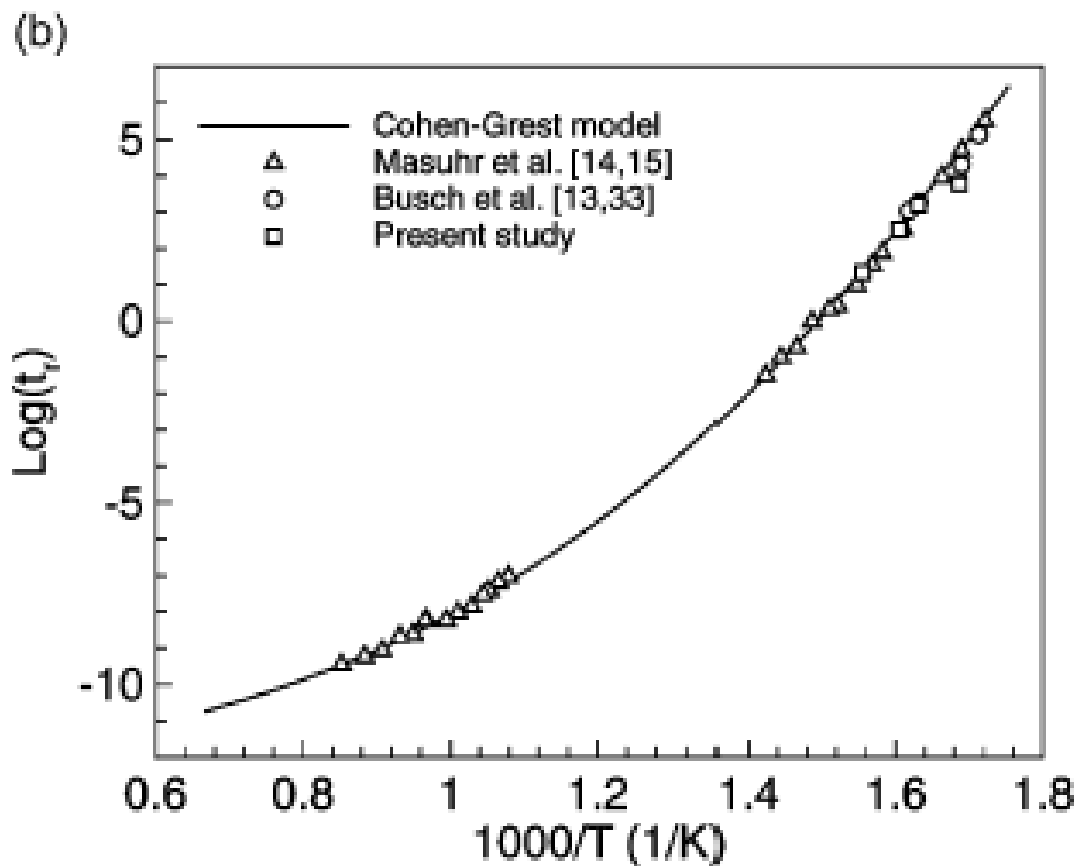
$$\dot{\epsilon} = \omega_0 \exp\left(-\frac{\Delta G_m}{kT}\right) \left(\frac{\sigma \Omega}{kT}\right)$$



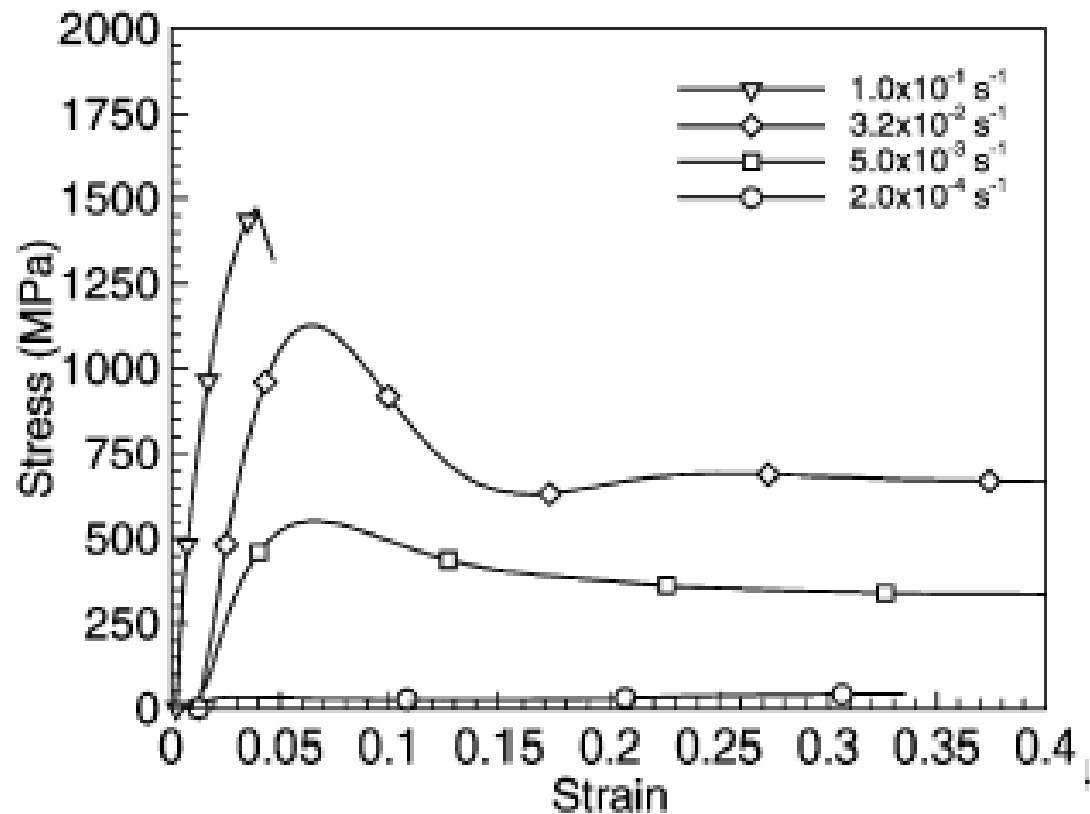
# Représentation d'Angell



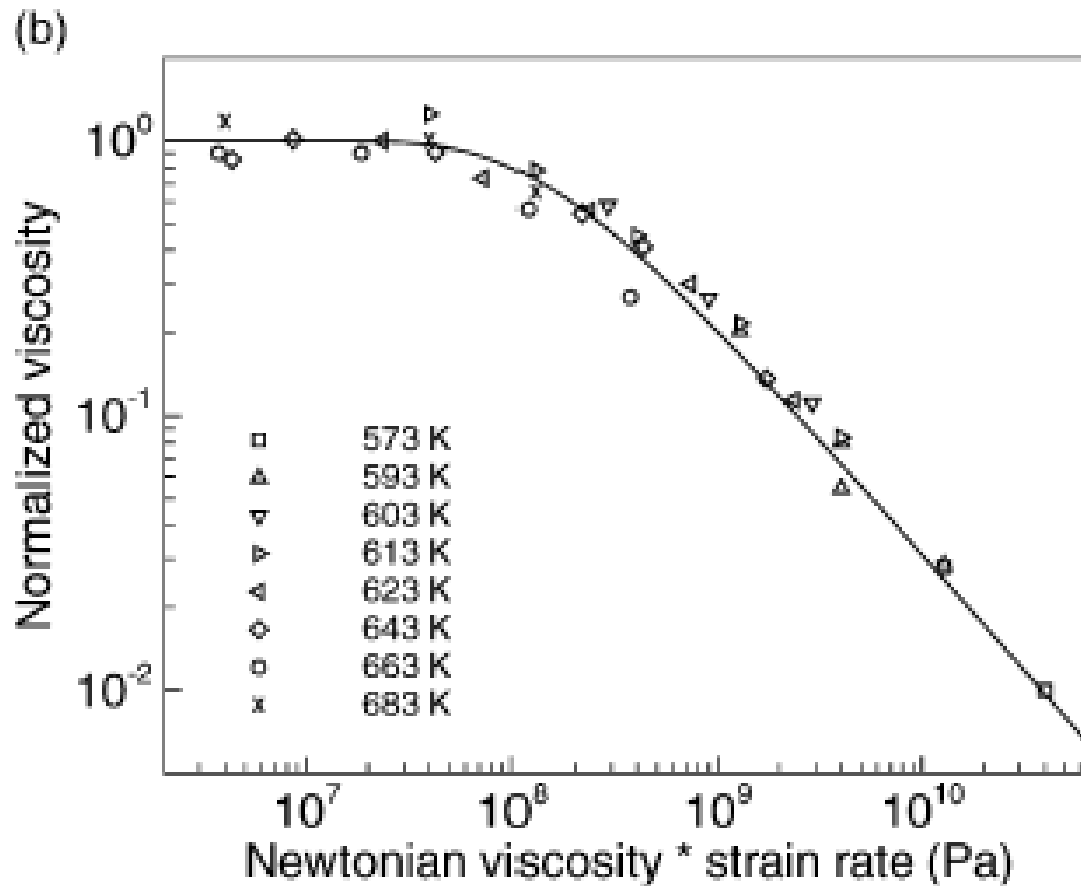
# Verres métalliques

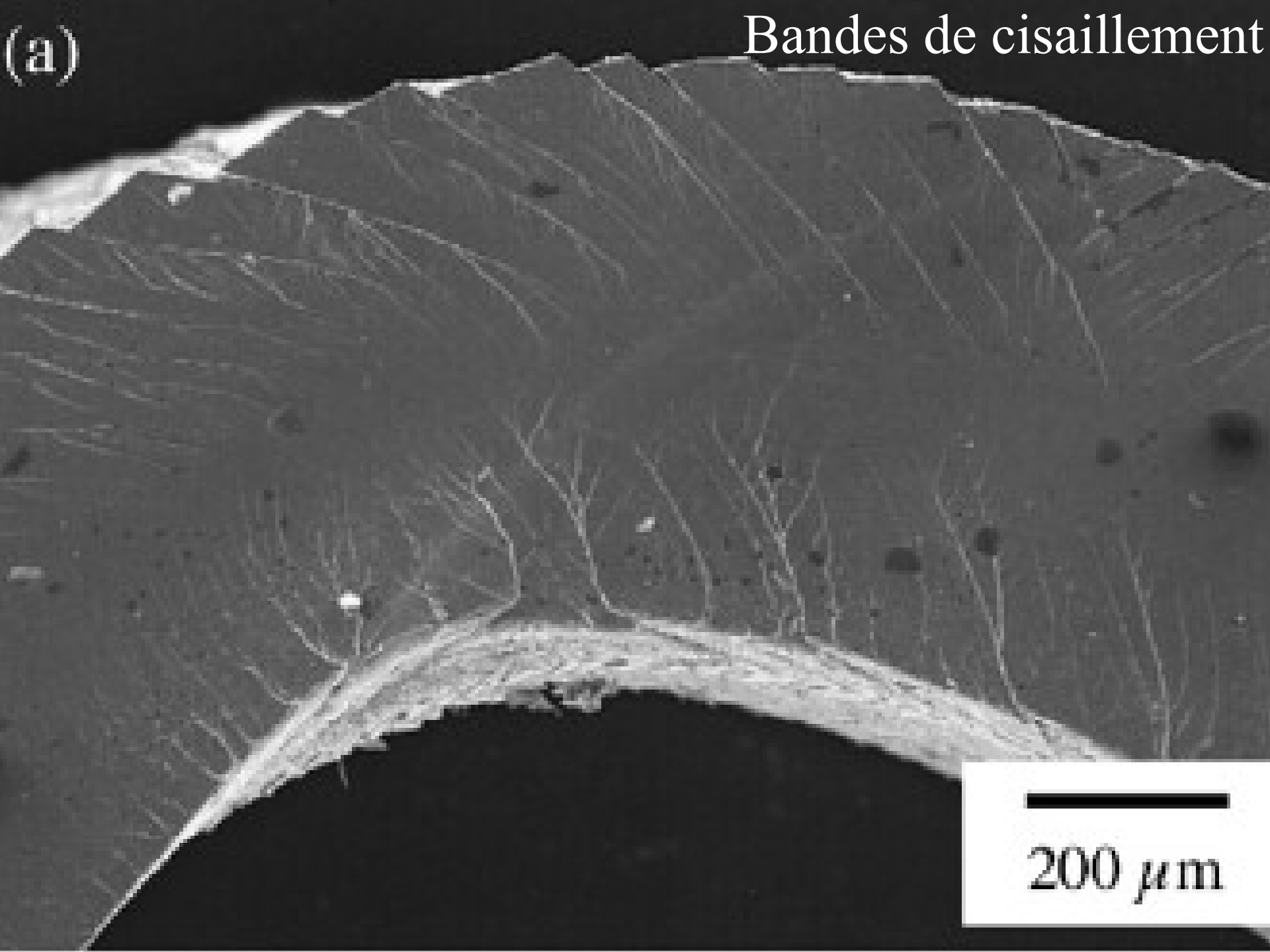


# Déformation à taux constant



# Déformation homogène





(a)

Bandes de cisaillement

200  $\mu\text{m}$

# Échauffement

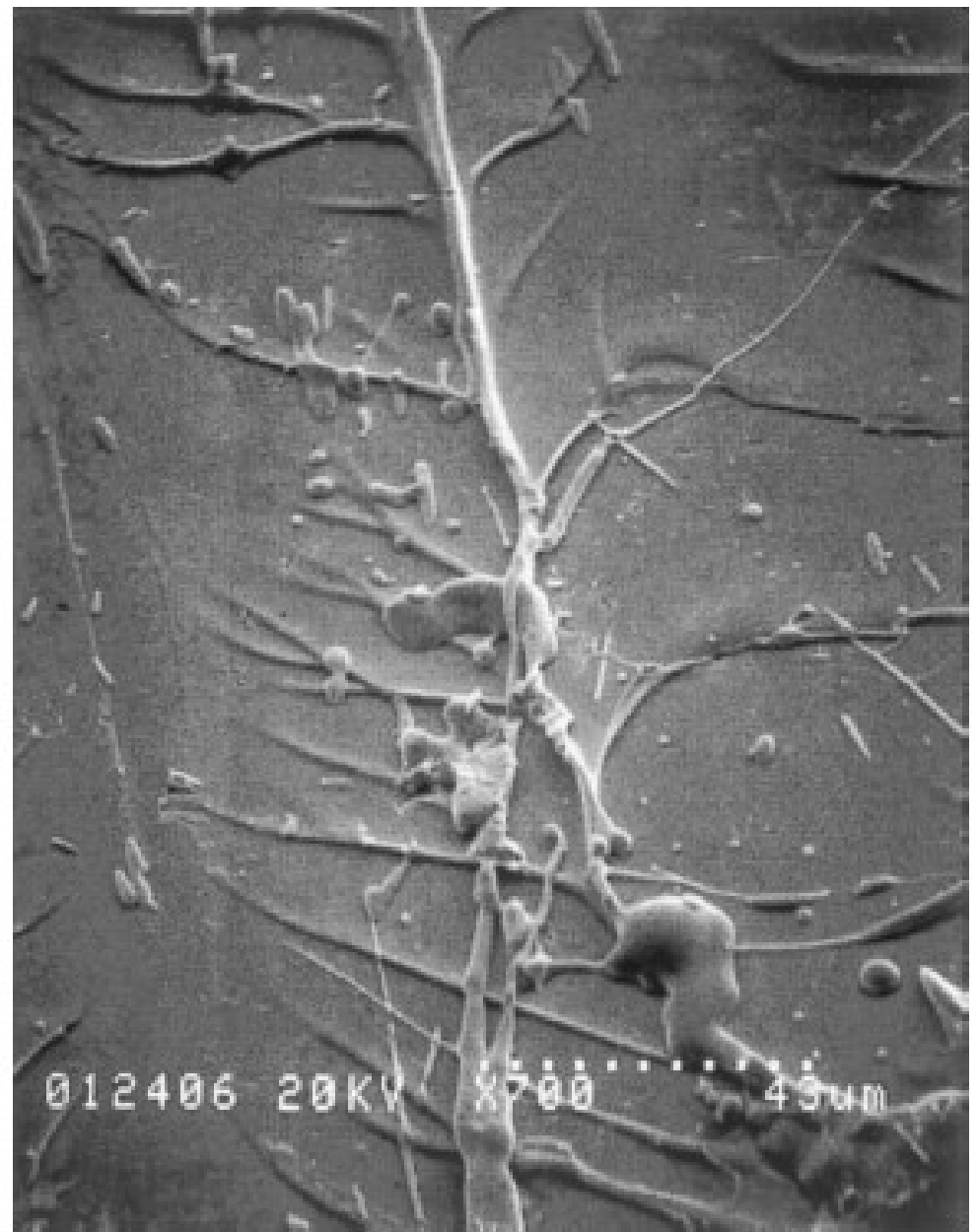
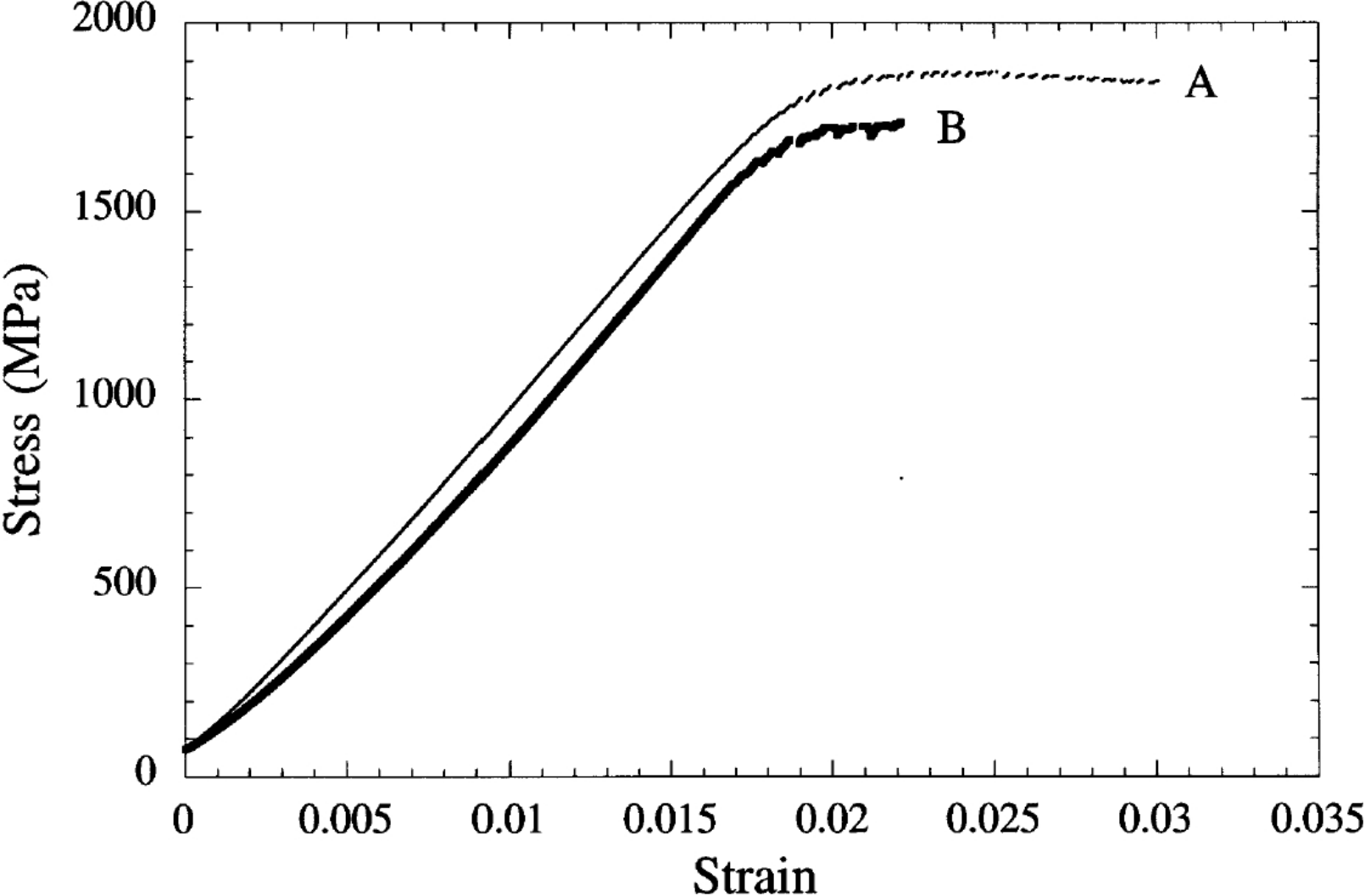


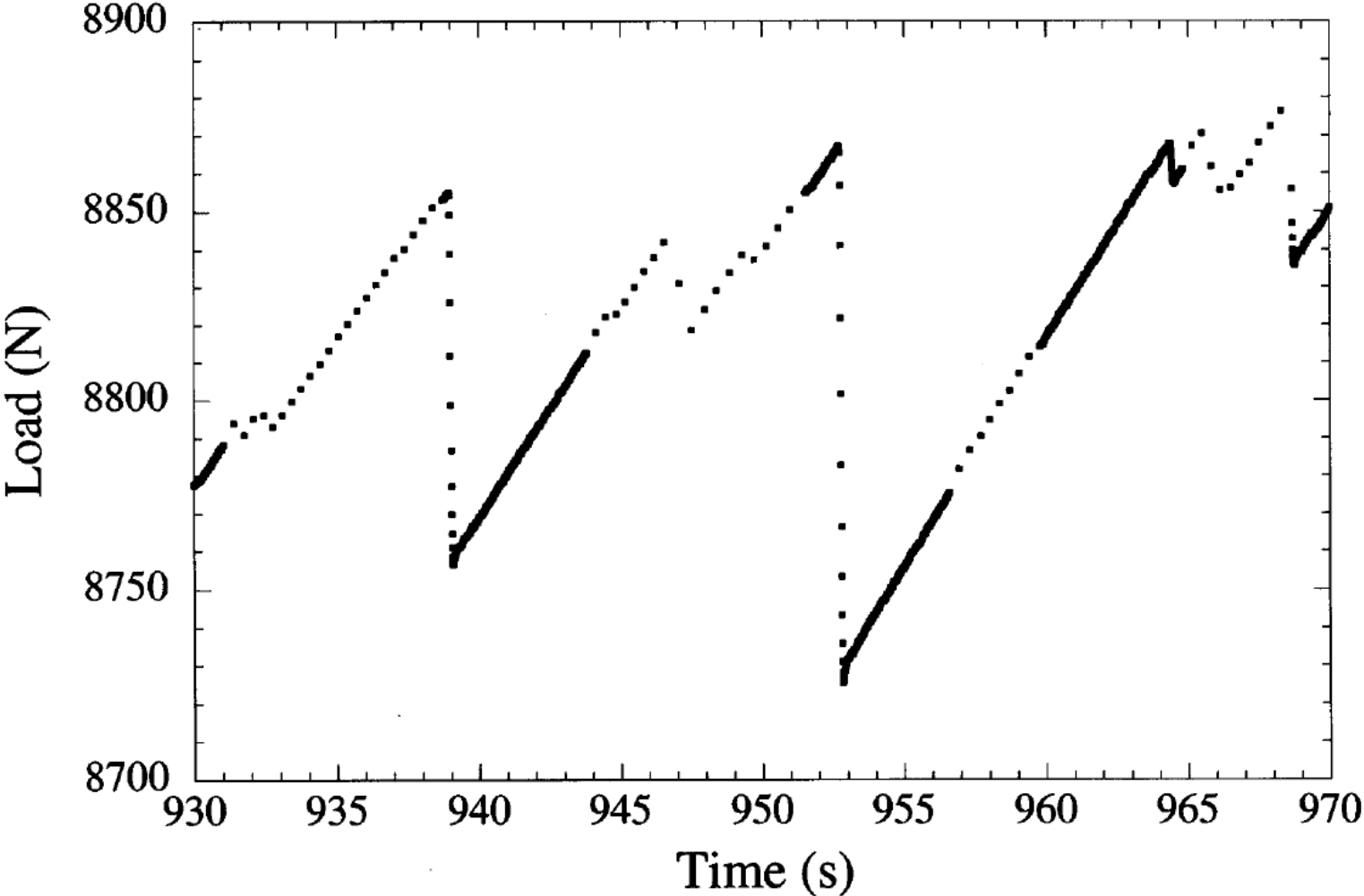
Fig. 5. Scanning electron micrograph of the fracture surface of a Pd<sub>40</sub>Ni<sub>40</sub>P<sub>20</sub> sample failed in uniaxial compression.



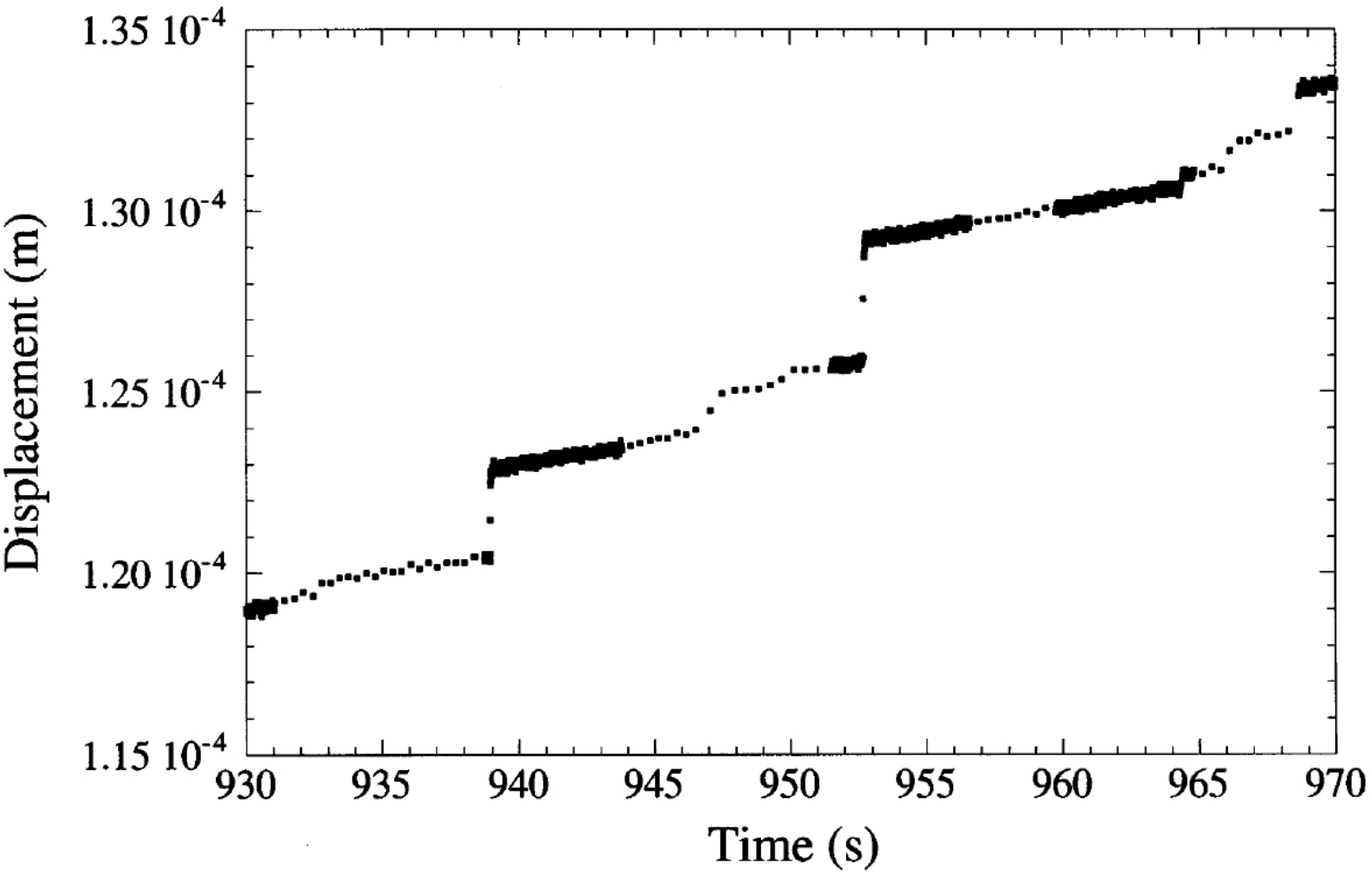
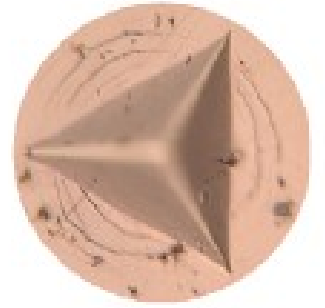
# Intermittence



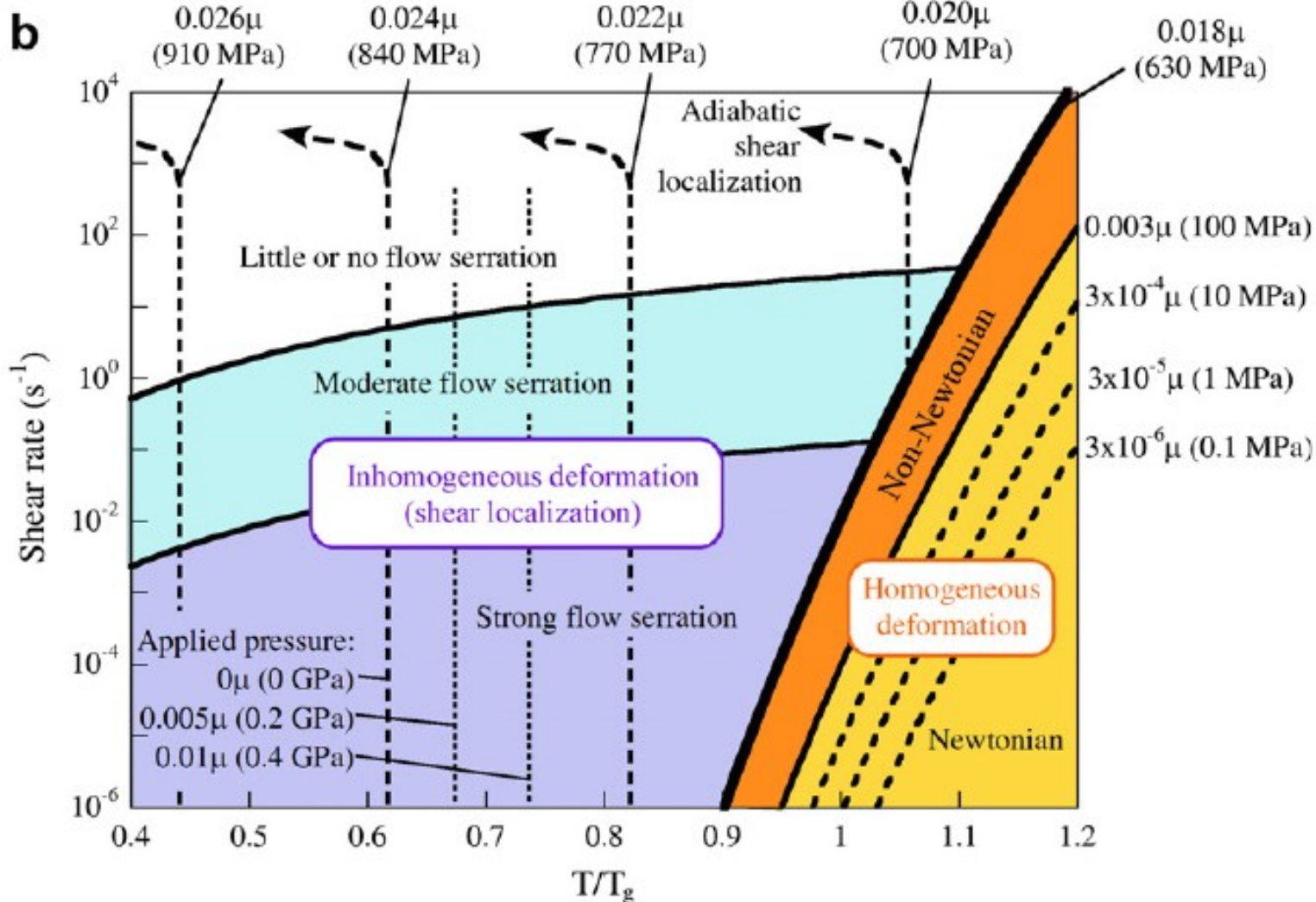
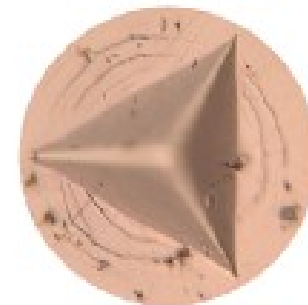
# Intermittence



# Nano-indentation: Intermittence

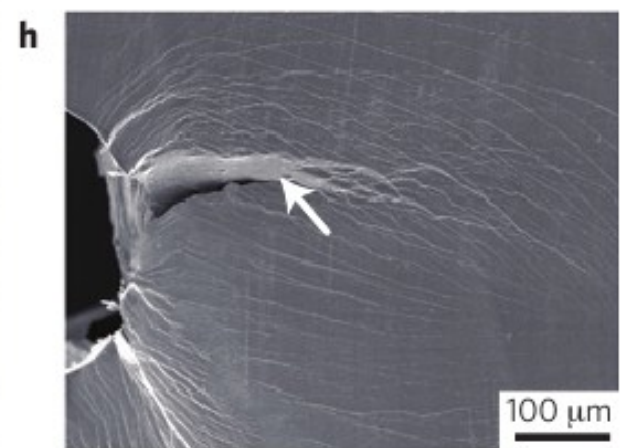
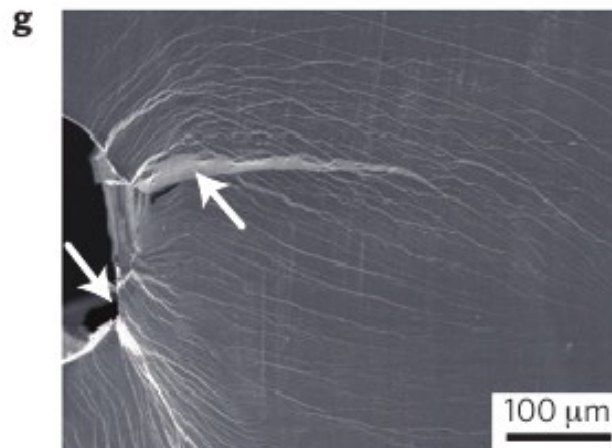
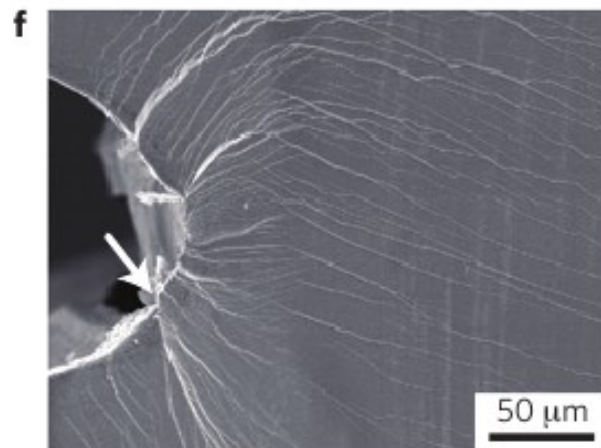
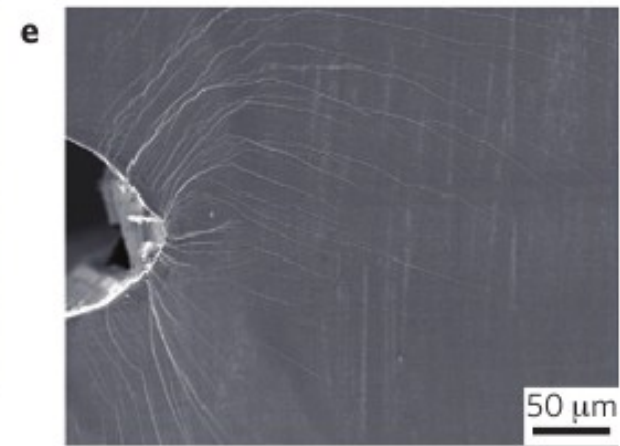
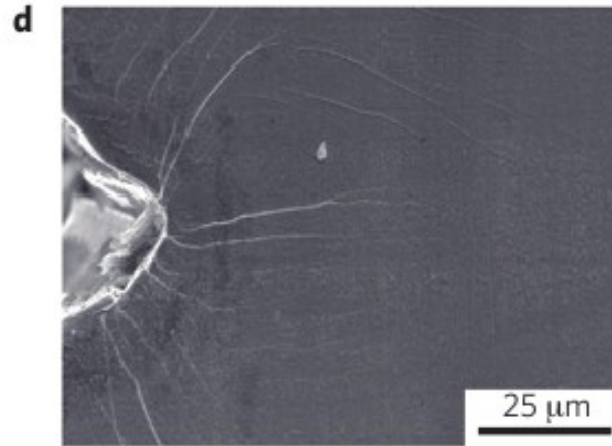


# Carte de déformation



Schuh *et al*,  
Acta Mat. 55, 4067 (2007)

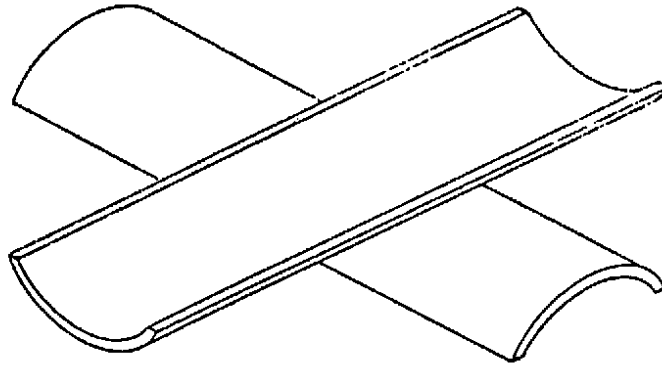
# La fracture d'un verre



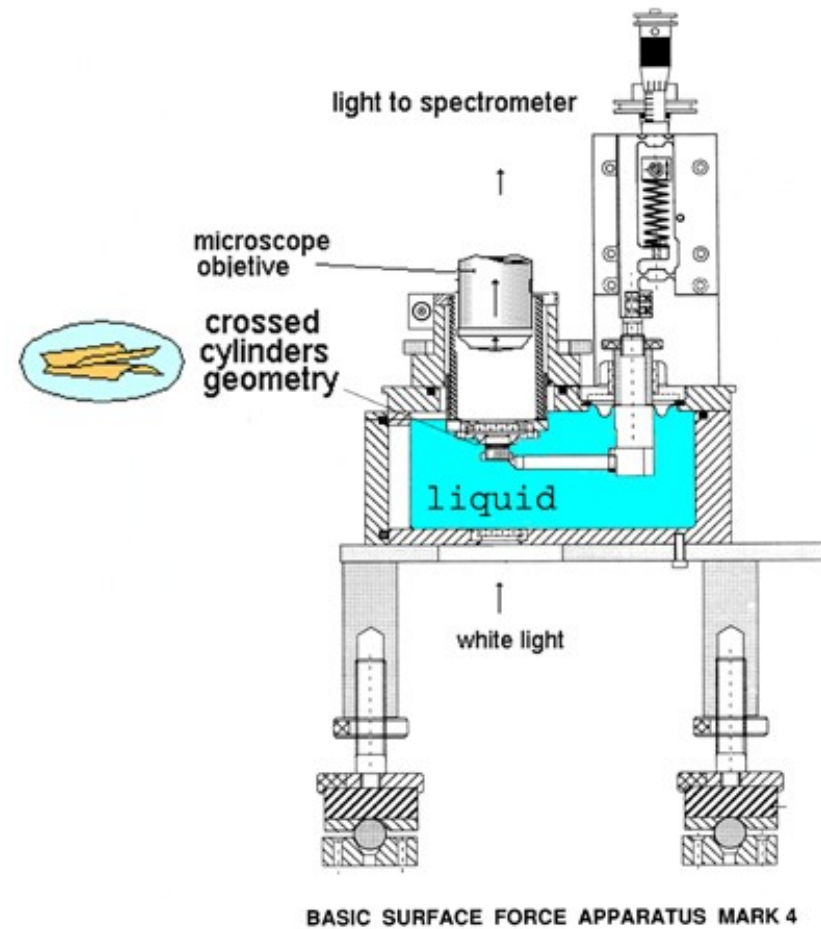
# Force entre deux surfaces

Lames de mica  
collées sur des demi-cylindres

- contact atomiquement plan
- en milieu humide ou non
- une lame fixe
- une montée sur ressort

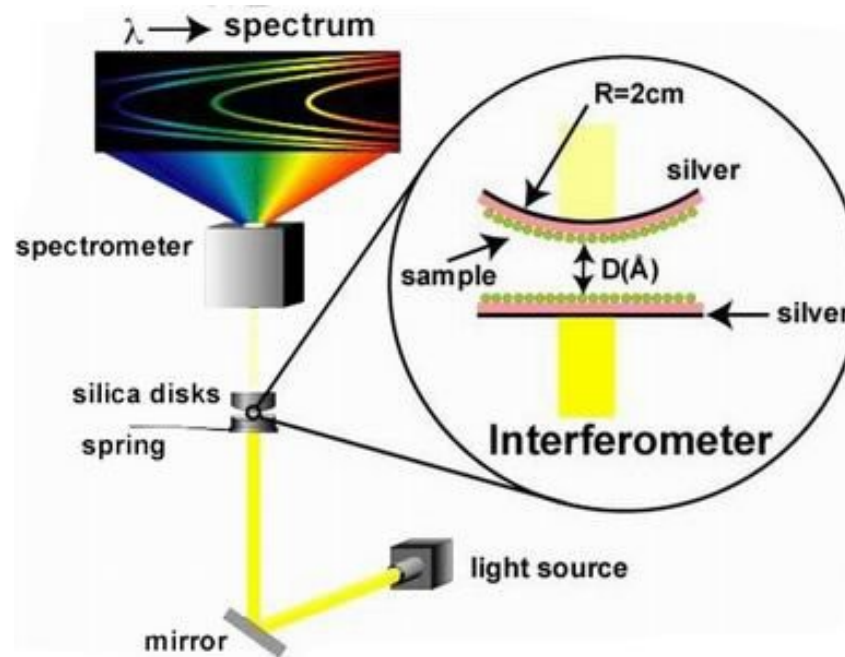


**FIGURE 1.** Arrangement of crossed cylinders. Molecularly smooth mica sheets about  $3\ \mu\text{m}$  thick are glued to cylindrical glass formers of radius of curvature about 1 cm. The back surfaces of the mica are lightly silvered so that the separation between the surfaces may be studied by multiple beam interferometry.

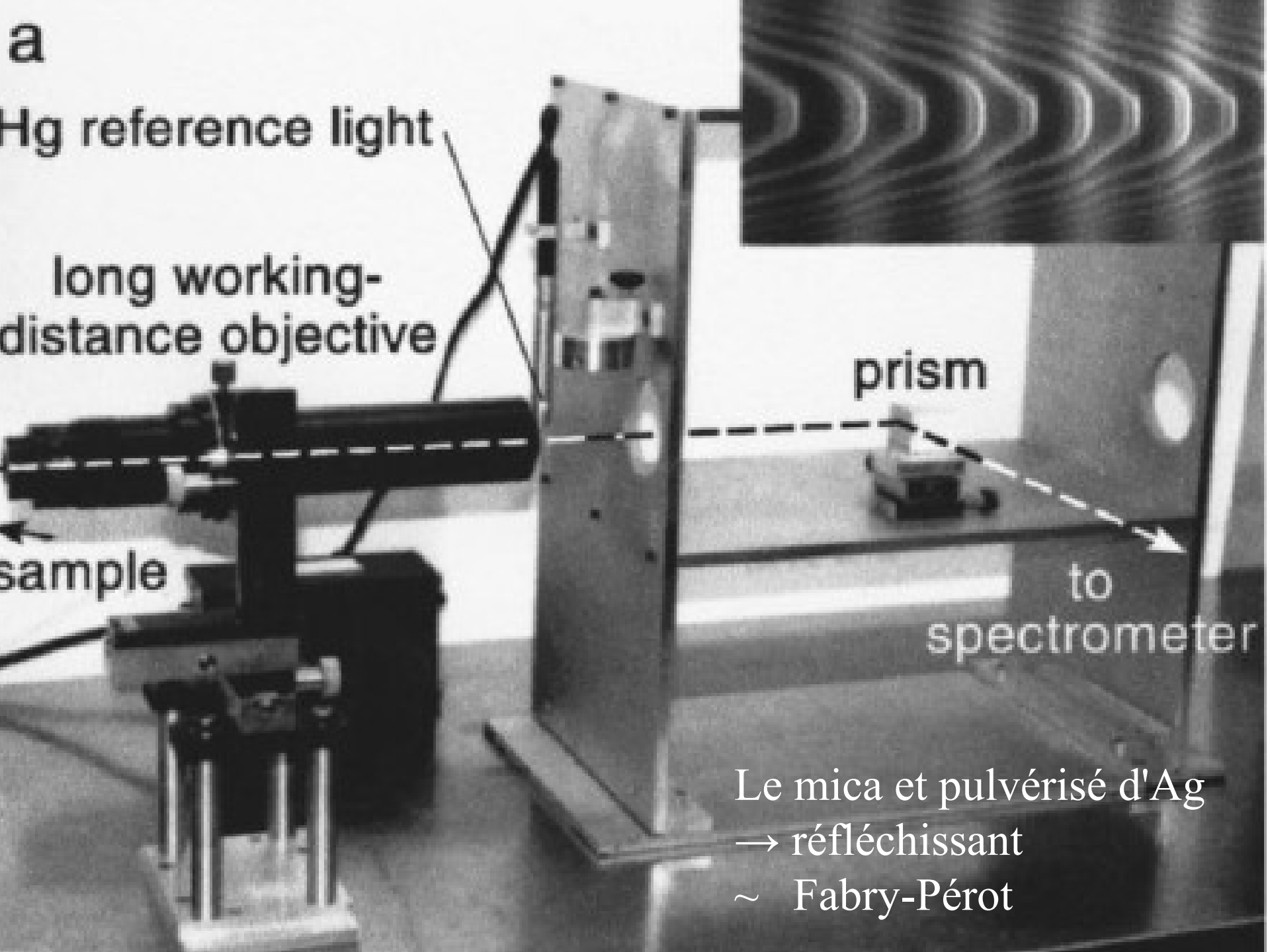


SFA = Surface Force Apparatus

# Interférométrie

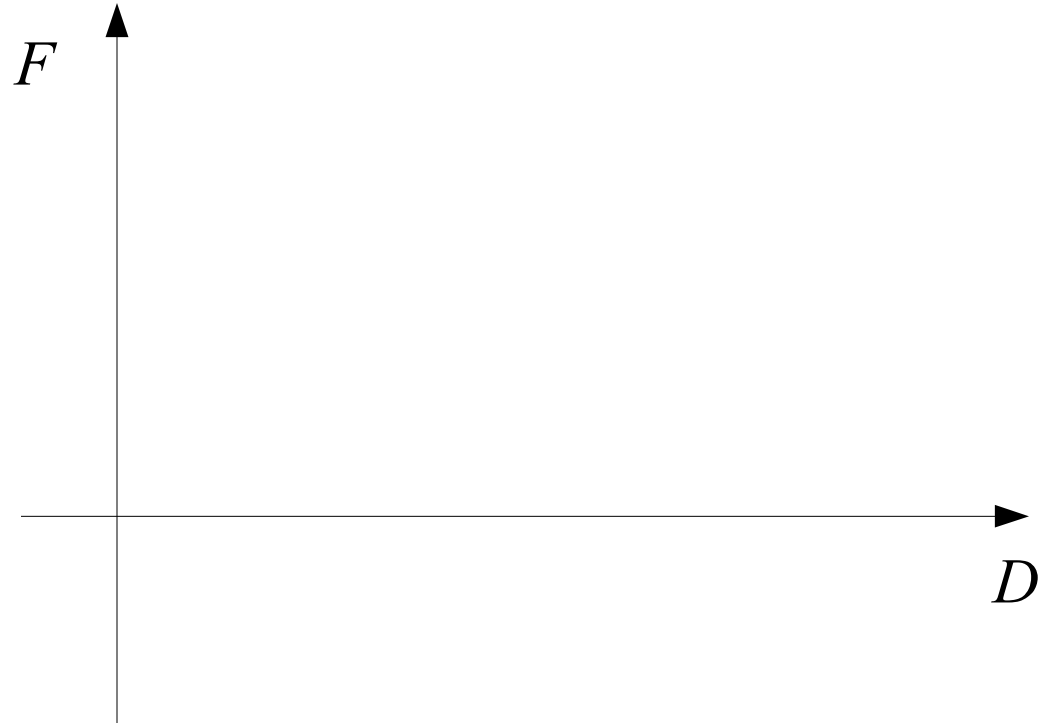


Le mica et pulvérisé d'Ag  
→ réfléchissant  
~ Fabry-Pérot





À quoi doit-on s'attendre ?

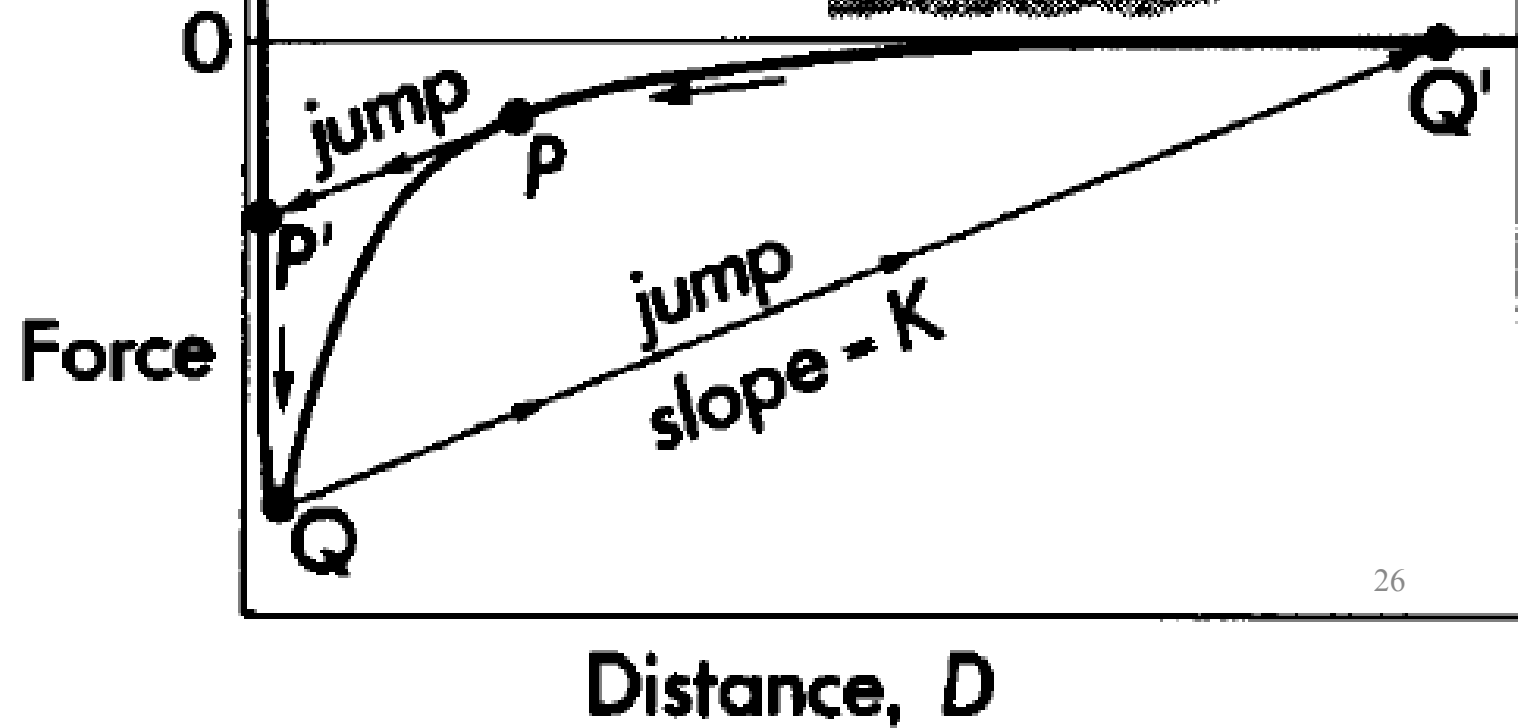
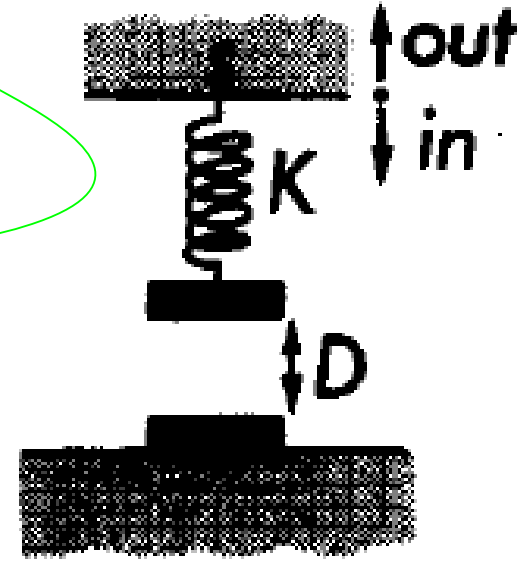


# van der Waals

Constante de Hamaker

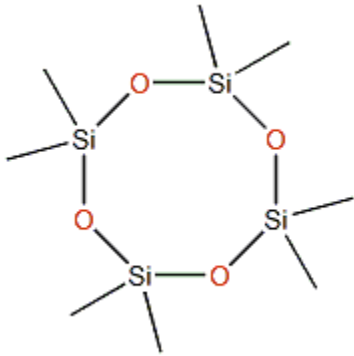
$$\sim 1/\epsilon^2$$

$$W(D) = -\frac{A}{12\pi D^2}$$



# En présence de liquide...

Horn-Israelachvili 1981



OMCTS  $[(\text{CH}_3)_2\text{SiO}]_4$

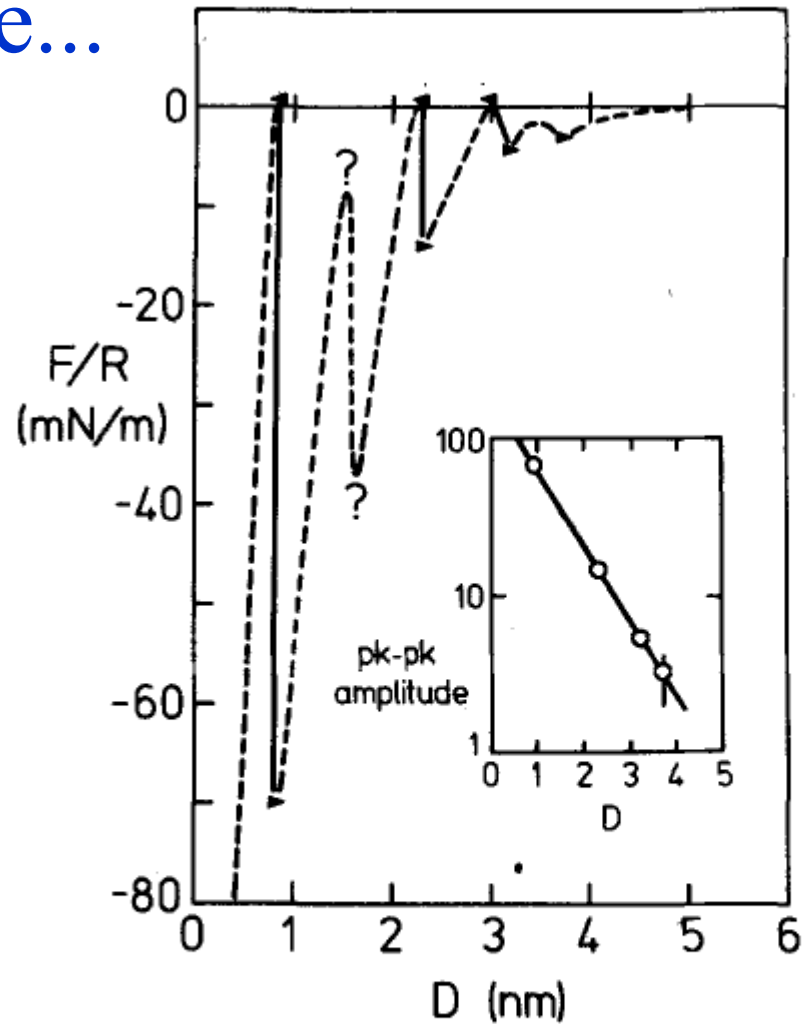
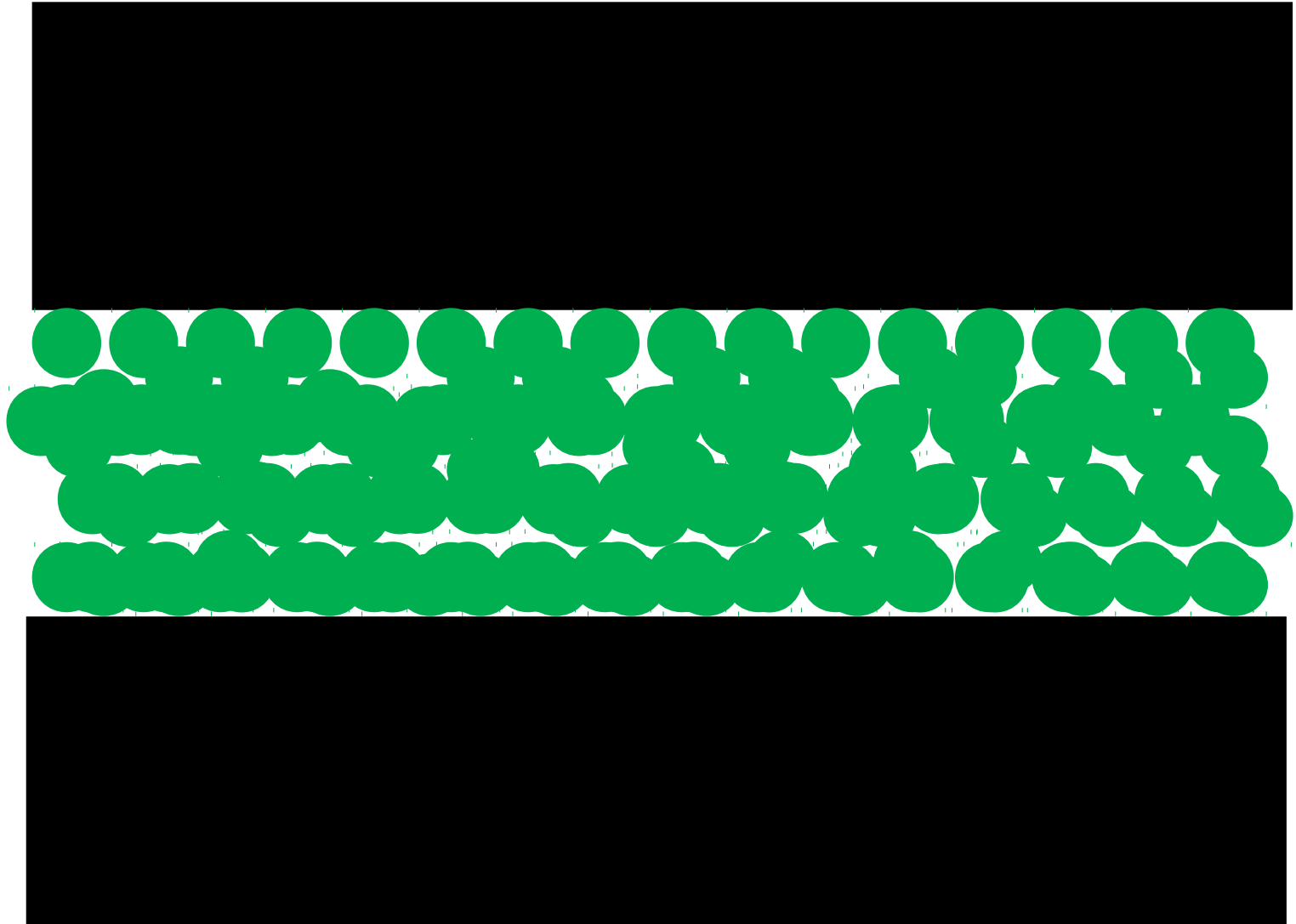
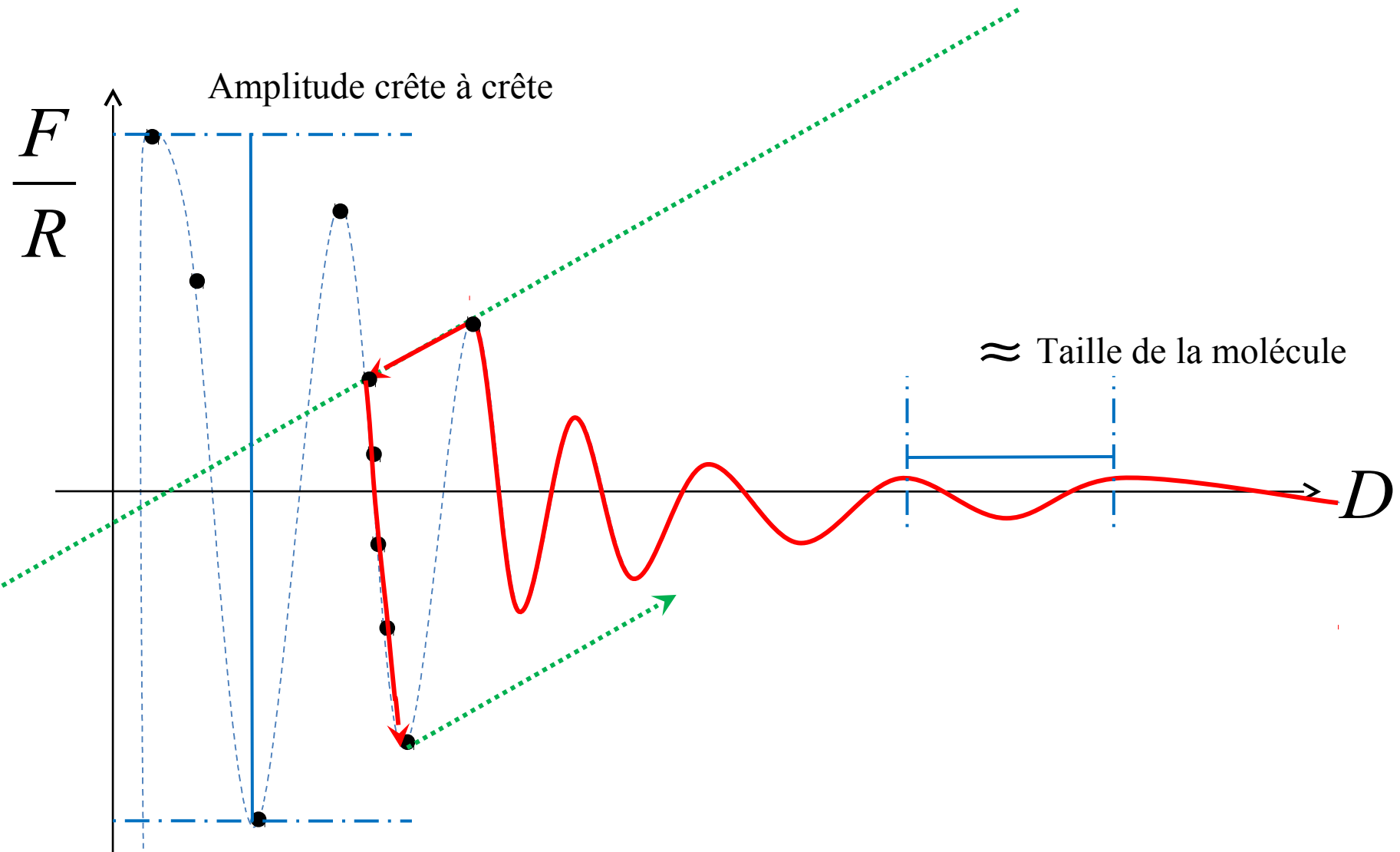


FIG. 7. Measured forces between two mica surfaces in OMCTS (the same experiment as Fig. 1) partially saturated with water. The dashed regions are experimentally inaccessible. In fully water-saturated OMCTS the force was everywhere attractive, so no oscillations could be measured.

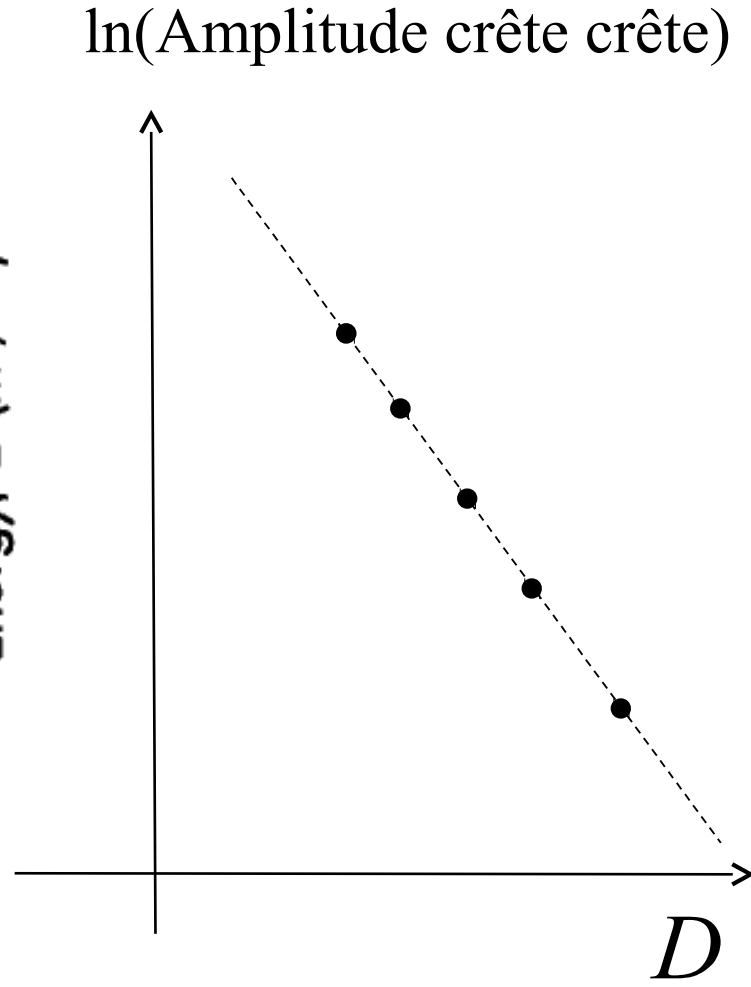
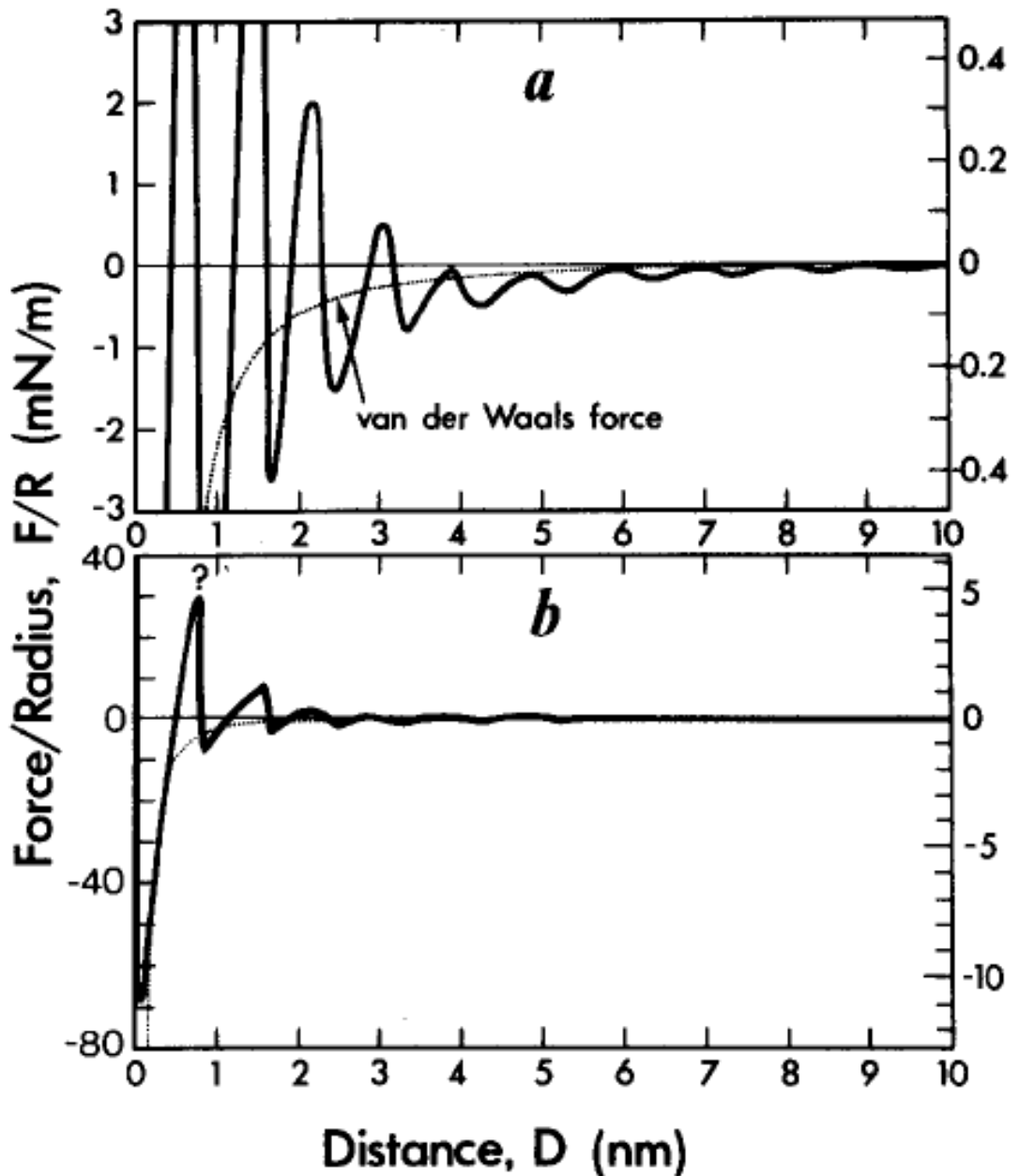
# Transitions liquide-liquide



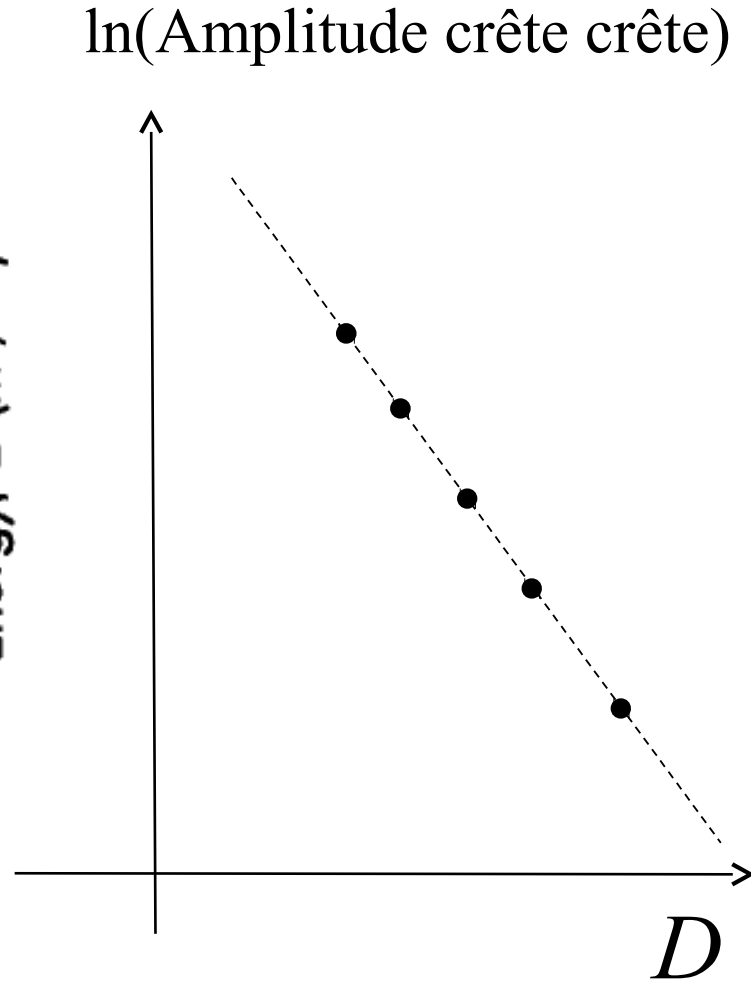
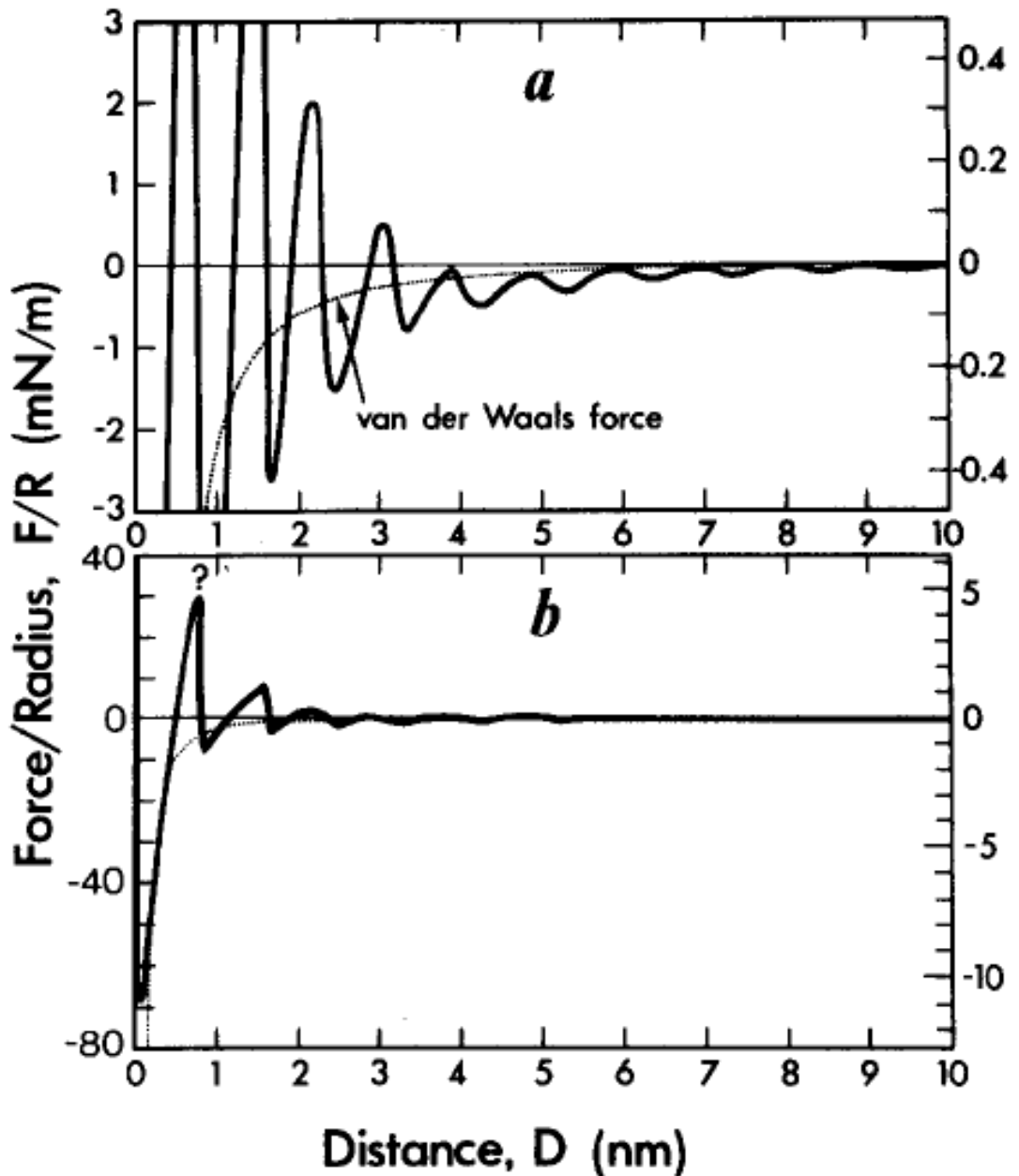
# Force effective entre surfaces



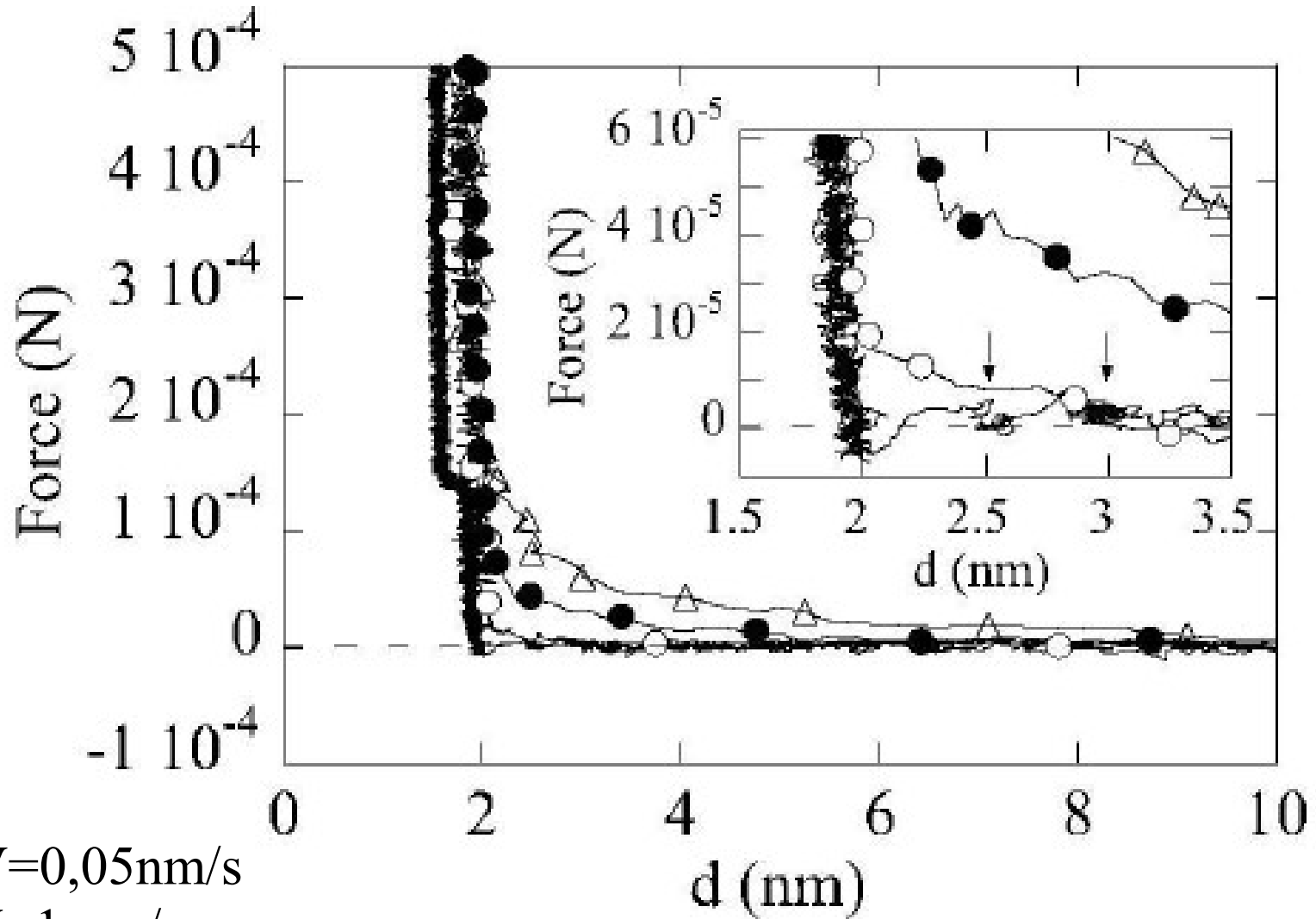
# Force effective entre surfaces



# Force effective entre surfaces



# Un autre exemple : alcanes confinés



- $V=0,05\text{nm/s}$
- $V=1\text{ nm/s}$
- $V=5\text{nm/s}$
- △—  $V=10\text{nm/s}$